Determination of sediment characteristics through cone penetration test in shallow marine areas using electrical compression cones

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The cone penetration test (CPT) is a simple technique which can be used for compaction studies in soft clay and fine-to-coarse grained sand. The equipment consists of mechanical, electrical, electronic and hydraulic units, and a coiling system. Data on tip resistance and sleeve friction are collected, which in turn provide the friction ratio, that is used for the textural classification of soils/sediments. Tip resistance and sleeve friction give an idea about the sediment density, which further helps in proper planning and design in shallow marine areas. The CPT is accurate and time dependent rather than vibrocoring.

The cone penetration test (CPT) was designed and developed in Europe, but has gained increasing importance in other parts of the world, especially in connection with sediment characterization and compaction studies. The CPT is a simple test that is widely used in soft clay and fine-to-coarse-grained sand. CPT has more advantages than the conventional way of drilling boreholes both on land and in water, as it is less time-consuming and cost-effective. Generally, mechanical and electric cone penetrometers are widely used for marine and land geotechnical investigations. The electric penetrometer is an improvement over the mechanical one. The electric penetrometer has many advantages and has a range of applications for marine sediment investigation. The repeatability of the cone test is good. Further, a continuous record of penetration results reflects the nature of sediment stratification better[1–8]. In this note, the results of a CPT carried out in a shallow marine area using electrical compression cones are analysed. Further, a classification of marine sediments is also carried out using electrical CPT results.

Methodology for electrical CPT

The equipment for CPT consists of mechanical, electrical, electronic and hydraulic units and a coiling system. The length of the coil depends upon the required depth of sediment investigation. The tip of the coiling system, consisting of a cone with an apex angle of 60° and a diameter of 35.7 mm, is pushed with the help of the hydraulic unit at a rate of 2 cm/s into the sediment. The diameter of the coil and the cone should be the same. Usually the cone has three types of sensors depending on the type of sediment investigation and type of sensors based on the objectives of the project. For the present study, a tip resistance sensor and sleeve friction sensor (pore pressure sensor is not needed in shallow marine conditions, as the pore pressure is negligible) were used. Data were collected on tip resistance and sleeve friction on a continuous push of electronic rods through the sediment at a maximum tip resistance of 5000 kPa and sleeve friction of 100 kPa. The continuous record of these data is the input into a micro computer for further analysis of sediments. The tip resistance and sleeve friction can be measured in terms of kPa/kN or MPa/MN. From the above two parameters, it is possible to find out the friction ratio which is expressed in percentage. Friction ratio (R_f) is expressed by a simple formula:

$$R_f = (f_s/q_c) \times 100,$$

where q_c is the tip resistance and f_s the sleeve friction.

Friction ratio helps in the textural classification of the sediment and tip resistance and sleeve friction enable to determine whether the sediment is loose, medium or dense. The sleeve friction measurement reflects the variation of lateral earth pressure in the sub-surface and can be used to investigate the effect of sediment compaction on the state of stress. Cone and sleeve friction measurements are strongly affected by the effective overburden pressure. A correction factor CM for the cone resistance was proposed[9].

$$CM = (100/m')0.5,$$

Table 1. Subtraction cones specification

Specification	10 t	15 t
Apex angle of cone (°)	60	60
Diameter (mm)	35.7	43.8
Projected area of cone (mm^2)	1000	1500
Length of friction sleeve (mm)	134	164
Area of friction sleeve (mm^2)	15000	22500
Maximum force on penetrometer (kN)	100	150
Maximum cone resistance q_c (MPa) (if f_s = 0)	100 (100 kN)	100 (150 kN)
Maximum sleeve friction f_s (MPa) (if q_c = 0)	6.6 (100 kN)	6.6 (150 kN)
Diameter of push rods (mm)	36	36

Table 2. Compression cones specification

Specification	10 t	15 t
Apex angle of cone (°)	60	60
Diameter (mm)	35.7	43.8
Projected area of cone (mm^2)	1000	1500
Length of friction sleeve (mm)	134	164
Area of friction sleeve (mm^2)	15000	22500
Maximum force on penetrometer (kN)	100	150
Maximum cone resistance q_c (MPa) (if f_s = 0)	100 (100 kN)	100 (150 kN)
Maximum sleeve friction f_s (MPa)	1 (15 kN)	1 (22.5 kN)
Diameter of push rods (mm)	36	

Table 3. General information

Rate of penetration	20 ± 5 mm/s
Maximum inclination	15°
Sensors	Cone resistance, sleeve friction, inclination and depth Pore water pressure (only for cone penetration testing with pore pressure (CPTU)) with a maximum reach of 1, 2 or 5 MPa. In the UK, pore water measurements up to 4 MPa are common, especially in chalk.
Position of thrust machine	At least 1 m from previous CPT, or at least 20 times the diameter of a previous borehole.
Level of thrust machine	Vertical ± 2°
Distance between measurements	Maximum 20 mm
Calibration	Every 3 months or 3000 m of sounding
Maximum wear	Angle of cone: 60 ± 5° Sleeve: 35.7 ± 0.4 mm
Symbols used in some cone calibration certificates	*C*10, 10 t compression cone; *C*15, 15 t compression cone; *S*10, 10 t subtraction cone; *S*15, 15 t subtraction cone; *C*, measurement of cone (tip) resistance; *F*, measurement of sleeve friction; *P*, measurement of pore water pressure; Example: Cone number, S10–CF.038 indicates 10 t subtraction cone, number 038, with measurement of tip resistance and sleeve friction.

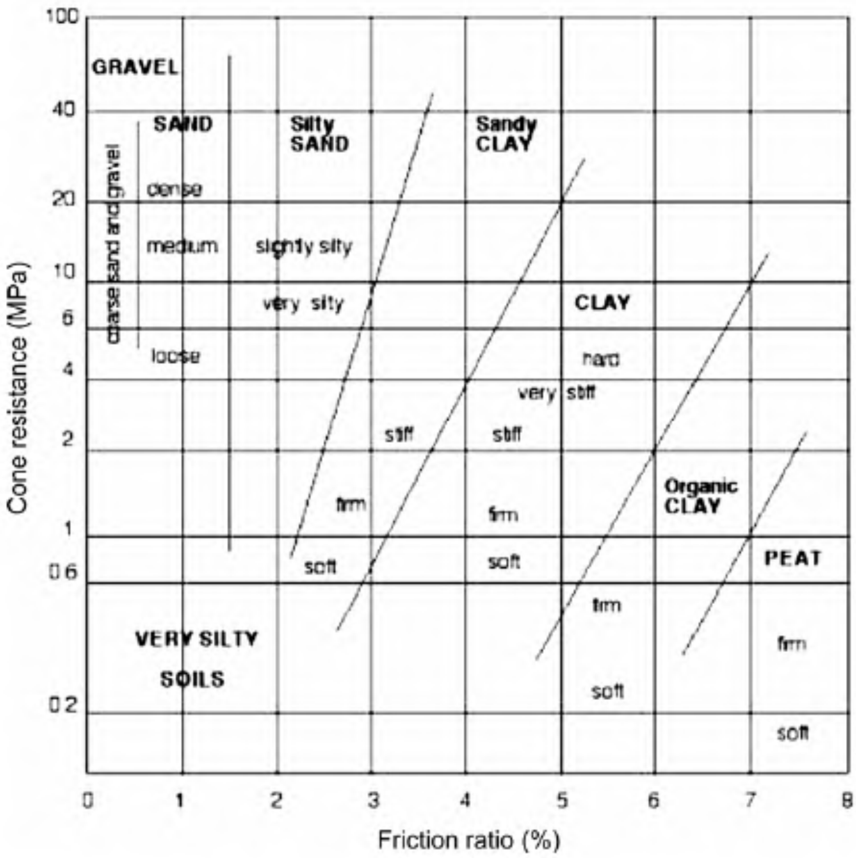

Figure 1. Chart for soil classification[10].

where m' is the mean effective stress which can be determined from the relation

$$m' = v' (1 + 2K_0)/3,$$

where v' is the vertical effective stress and K_0 the coefficient of the lateral earth pressure at rest.

Cone configuration

Currently, five cone configurations are in use: (a) mechanical or Dutch cone (provides both point resistance and skin friction; (b) electrical friction (using a strain gauge to measure the tip resistance and sleeve friction), (c) electric piezo (to measure the pore water pressure); (d) Electric piezo/friction (to measure the point resistance, sleeve friction and pore pressure) and (e) Seismic cone (to compute shear wave velocity from a surface shock).

In the present study an electric cone has been used, which consists of an electronic inclinometer to measure the deviation of the vertical alignment of the cone. The CPT test should be carried out with an inclination less than 15°. A particular advantage is to obtain a continuous profile as long as it encountered hard sediment or rock. Further, the test is rapid when the electronic data acquisition is used.

Classification of cone penetrometers

Generally cone penetrometers can be divided into subtraction and compression types. The subtraction cone measures the total force on the penetrometers (sleeve + tip) and the tip resistance. Sleeve friction is calculated by subtracting the tip resistance from the total force. A compression cone measures tip resistance and sleeve friction separately. In compression cones the sleeve friction is obtained separately so that the maximum value for the friction is 1 MPa. But there is no restriction on the sleeve friction for subtraction cones (sleeve friction is calculated from total force and tip resistance). It can be concluded that subtraction cones are used in areas where stiff clay is present with a sleeve friction grater than 1 MPa. In this study, a compression cone penetrometer has been used with different capacity such as 10 and 15 t (Tables 1–3)[10].

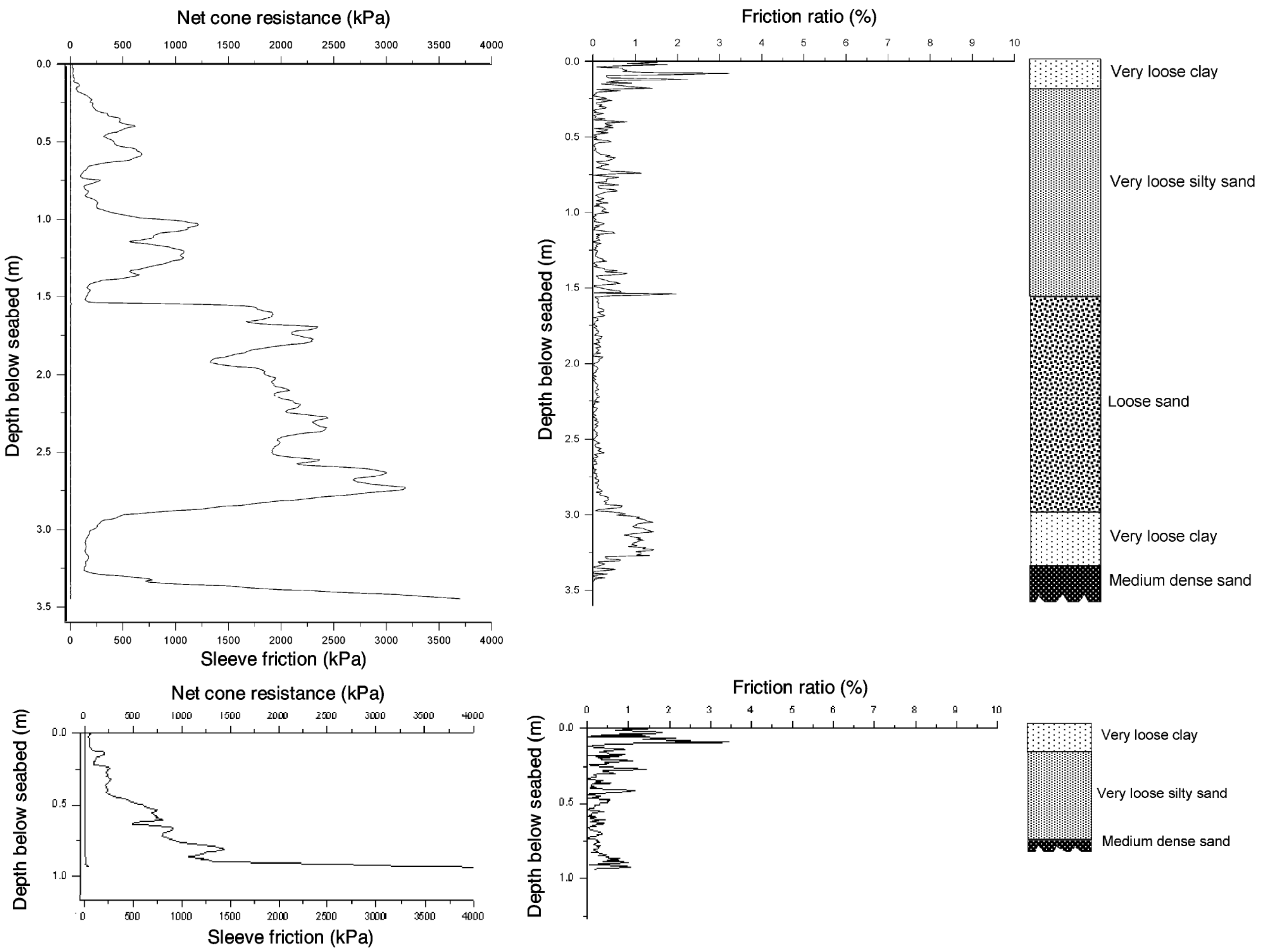

Figure 2. CPT results and their interpretation for (***a***) 3.4 m and (***b***) 1 m sediment thickness.

Evaluation of cone penetration results

The electrical compression penetrometers can evaluate: (i) Sub-surface stratification of sediment; (ii) Sediment type (sandy, silty or clayey); (iii) Sediment density and *in situ* conditions, and (iv) Shear strength parameters.

The results obtained from the CPT can be directly used for designing pile foundation in sandy and gravelly sediments. Further, it can be indirectly used for calculating shear strength for piling in clayey sediments. The friction ratio can be used for sediment classification. Figure 1 shows a sediment classification chart for a standard electronic cone[10]. Figure 2 *a* and *b* provides two sample data of the CPT results, where the test has been carried out in shallow marine areas of Abu Dhabi, UAE. Figure 2 *a* and *b* shows sample data obtained from electrical compression cone, which explain stratification, type and sediment density. Sand usually has a friction ratio of less than 2%, whereas for clay it is more than 2%. Peat may have a friction ratio of more than 5 or 6%. This note throws light on the importance of the CPT for its accuracy of testing, delineation of various sediment strata, sediment density, etc. Further, the CPT has various advantage like accuracy, less time-consuming (2 cm/s), directly obtaining density parameters, etc. Thus it can be concluded that CPT is well-suited for pile design than vibrocoring in shallow marine areas.

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